Technical Memo

ANL/EES-TM-313

REVISED COSTS AND AIR QUALITY IMPACTS OF ALTERNATIVE NATIONAL AMBIENT AIR QUALITY STANDARDS FOR PARTICULATE MATTER

TECHNICAL SUPPORT DOCUMENT

ARGONNE NATIONAL LABORATORY

Energy and Environmental Systems Division

Operated by

THE UNIVERSITY OF CHICAGO for U. S. DEPARTMENT OF ENERGY

under Contract W-31-109-Eng-38

[redacted]

Printed in the United States of America. Available from National Technical Information Service, U. S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue, Argonne, Illinois 60439

ANL/EES-TM-313

REVISED COSTS AND AIR QUALITY IMPACTS OF ALTERNATIVE NATIONAL AMBIENT AIR QUALITY STANDARDS FOR PARTICULATE MATTER

TECHNICAL SUPPORT DOCUMENT

by

K.L. Brubaker and A.E. Smith

Energy and Environmental Systems Division

August 1986

work sponsored by

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air Quality Planning and Standards
Ambient Standards Branch

CONTENTS

FIGURES

TABLES

TABLES (Cont'd)

1 INTRODUCTION

The analysis system used to estimate air quality impacts and direct industrial costs associated with the implementation of alternative national ambient air quality standards for particulate matter was described in detail in a previous report.[1] During that study, a number of desirable changes and modifications to the system were identified but not made due to program constraints. Several of these would eliminate remaining inherent inconsistencies, and others would extend the usefulness and flexibility of the system. In particular, changes were made which addressed all four of the potential problem areas discussed in Section 6.2.2 of Ref. 1. This report documents the changes made in the particulate matter analysis system since the previous work was completed and presents the results of a reanalysis of the air quality impacts and direct industrial costs related to national ambient air quality standards for particulate matter.

The basic steps in the analysis are the same as before:

1. Development of data bases.
2. Projection of future emissions.
3. Projection of future air quality.
4. Identification of nonattainment problem counties.
5. Development of control strategies for problem counties.

Figure 1.1 shows the structure of the new analysis system and the relationships between the various computer programs and data sets and illustrates the overall conceptual design of the system. Tables 1.1-1.3 give the actual names of the computer programs and files and, where appropriate, cross-reference them to Figs. 1.2A and 1.2B in Ref. 1. All operations above the upper dashed line in Fig. 1.1 relate to the development of base-year (1978) data. Operations between the two dashed lines relate to the projection of future quantities which are independent of the set of national ambient air quality standards (NAAQS) under consideration. Operations below the lower line depend on the specific set of NAAQS considered and must be rerun for each new NAAQS scenario.

A conceptual reworking of the initial parts of the old system was undertaken in order to remove a major inconsistency between the way air quality was projected and the way control strategies were developed. In the new system, source-specific coupling coefficients are computed as part of the first step and are used both in the projection of air quality and in the development of the control strategy. In addition, source classification code (SCC)-specific new-source control efficiencies were developed and used in the projection methodology in place of a single generic, new-source efficiency.

The national analysis is still done on a country-by-country basis; the use of subcounty areas has been eliminated in the new system. Emission projections are now made for both total suspended particulates (TSP) and particulate matter less than

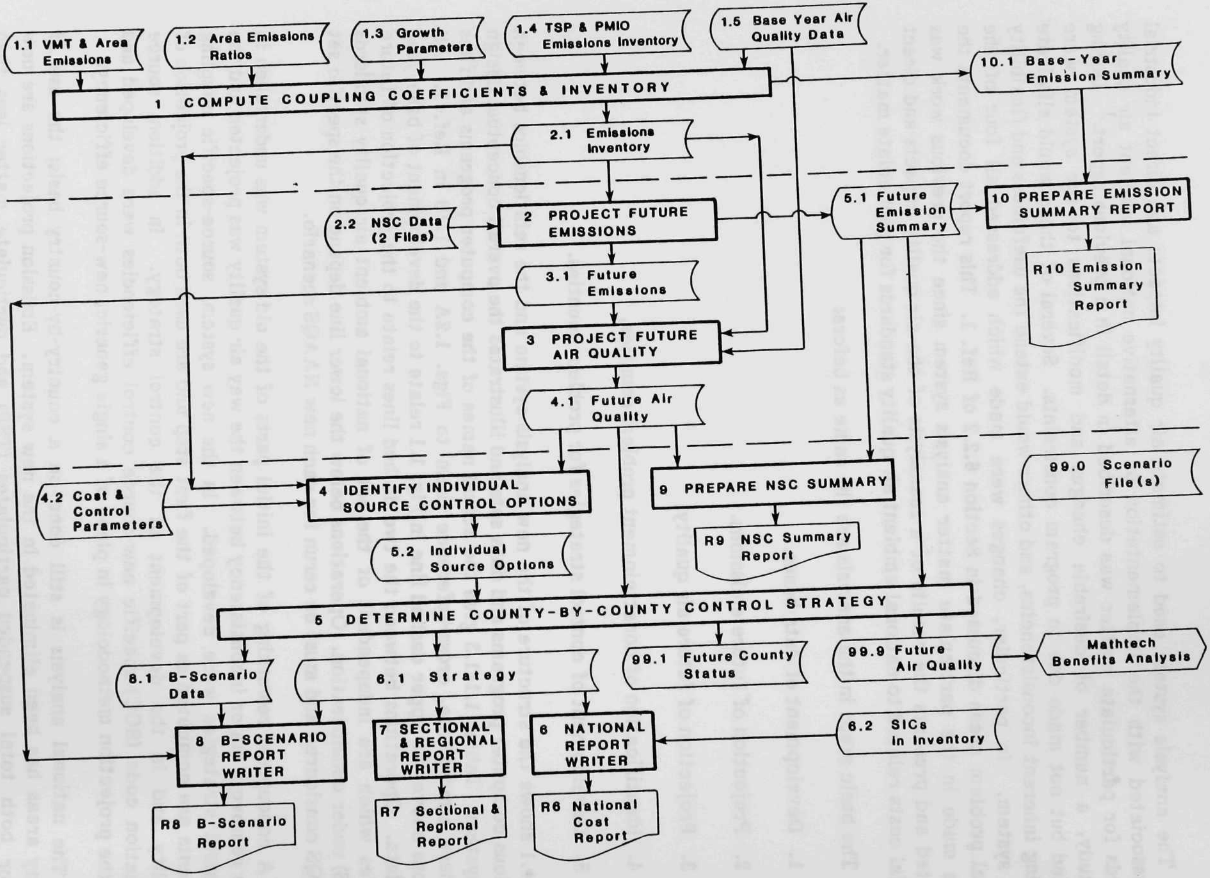

FIGURE 1.1 Overview of Analysis System

TABLE 1.1 Data Files

File Name	Key in Fig. 1.1	File in Ref. 1[a]
ANL-VMT	1.1	3.2 & 3.5
AREA-RATIO	1.2	3.4
ANL-GRFACT	1.3	3.7
INVIO-COUNT	1.4	3.3
TSPDV-JAN85	1.5	b
CCEMIS-X	2.1	-
CONTDEF	2.2	-
NSDFLT	2.2	-
FEMIS-XY	3.1	-
FAQ-XYZ	4.1	-
CSTDAT-MAY85	4.2	c
QSUMRY-XY	5.1	-
SCOPT-XYZW	5.2	-
STRAT-XYZW	6.1	-
SIC-LIST2	6.2	9.2
BSDATA-XYZW	8.1	-
BSUMRY	10.1	-
SXYZW	99.0	-
STATUS-XYZW	99.1	-
FAQUAL-XYZW	99.9	-

[a]Ref. 1, Fig. 1.2A.

[b]Similar to File 4.4 in Fig. 1.2A, revised as described in Section 2.1.

[c]Similar to File 7.2 in Fig. 1.2B, revised as described in Sections 2.2 and 2.3.

TABLE 1.2 Names of Computer Programs

Program Name	Key in Fig. 1.1
SEY.PUB.COUPLE	1
SEY-PB.PROJFE	2
SEY-PB.PROJFAQ	3
SEY-PB.SCOPTS	4
SEY-PB.STRATEGY	5
RAY-PGM.MAIN	6
RAY-PGM.MAINREP	7
RAY-PGM.REPORTC	8
RAY-PGM.REPORTB	9
RAY-PGM.REPORTA	10

TABLE 1.3 Report Files

Report File Name	Key in Fig. 1.1
NATIONAL-XYZW	R6
STATE-XYZW	R7
BSCEN-XYZW	R8
NSCSUM-XY'Z'W	R9
EMISUM-XY	R10

10 microns (PM10) for all years in the analysis period. Air quality projections are now made for all four measures of air quality considered: (1) observed 24-hour second-high TSP concentration, (2) annual geometric mean TSP concentration, (3) expected 24-hour second-high PM10 concentration, and (4) annual arithmetic mean PM10 concentration. Air quality projections are now also made for all years in the analysis period, eliminating the need for determining the "binding year" and "binding standard" concepts that were found to be ambiguous in the previous work. Projection of all four air quality measures for all analysis years also facilitates the estimation of benefits that accrue due to the

implementation of air quality standards, although that task was carried out by Mathtech, Inc., and is not discussed in this report.

For the most part, data bases previously developed were used again. The changes made, including changes to the air quality file and to the individual source control options file, are discussed in Section 2.

A discussion of the methodology for projecting future nonattainment, including a description of the new new-source control (NSC) algorithm and a review of the procedures used for the projection of emissions and the computation of coupling coefficients, is given in Section 3.

All years in the analysis period are now treated, instead of only one as in the previous system, and a multiyear control strategy is developed. In addition, a new algorithm for the development of the "least-cost" control strategy was developed and implemented in the new system. The methodology for control strategy development is described in Section 4.

Section 5 discusses the computations involved in the estimation of total costs and other quantities. Section 6 describes additional analyses, including the reduction of residual nonattainment and some sensitivity analyses. A summary of results is presented in Appendix B.

2 DEVELOPMENT OF DATA BASES

As indicated in the introduction, data bases developed and used in the previous work were used again, most without modification, in this study. The changes that were made are described in this section.

2.1 AIR QUALITY

Reference 1 describes the air quality data base used in the previous study and discusses the default procedure used to estimate the values of missing data. The same data base was used in the present study, but in the previous study, more than one set of air quality data was associated with some counties. The present study used a single set of air quality data composed of the maximum value available in the composite set for each measure of air quality. In the previous study a separate fraction, α, of the emissions from area sources had been assumed to affect each receptor in a given county. In a county with N sets of air quality data, up to N separate fractions of the unpaved municipal roads, one for each air quality data set, could have been controlled during strategy development. Each separate, controlled fraction contributed to the total cost. Under the present procedure, only one fraction α of the emissions from unpaved municipal roads in a particular county is available for control during strategy development. In addition, the default procedure used in the present study differs from the earlier one in that (1) new regression analyses were run and new regression coefficients determined and (2) consistency checks were made on the relative values of geometric and arithmetic means and on the values of all measures of air quality compared to corresponding background values.

Table 2.1 gives the regression equations used in the present study to estimate the values of different missing measures of air quality. All measures in the air quality dataset refer to TSP only, as do the variables appearing in Table 2.1. Once a complete set of TSP values was available for a given county, a check was made to see that all measures were above the relevant background level and that the arithmetic mean was greater than the geometric mean. Any measure less than background was replaced by the background plus 1.0 microgram/cubic meter ($\mu g/m^3$), except for the annual arithmetic mean, which was replaced by the background plus 2.0 $\mu g/m^3$. Also, at this stage the annual arithmetic mean was less than the annual geometric mean only for very small values of both; in such cases, the arithmetic mean was again replaced by the background plus 2.0 $\mu g/m^3$.

Once a complete and consistent set of measures of TSP air quality was available for a county, the PM10 annual arithmetic mean and expected second-high value were estimated by multiplying the corresponding TSP values by a conversion factor. The capability exists in the new analysis system to use state-specific factors, but in the present study a uniform value of 0.46 was used. A value of 0.55 was used previously.

TSP annual and 24-hour background values available from the previous work were used. A different procedure was incorporated for estimating PM10 background values, however. Previously, the same factor used to convert other air quality values was used

TABLE 2.1 Regression Equations for TSP Air Quality Data

Equation[a]	r^2	Independent Variable Average	Independent Variable Standard Deviation	Dependent Variable Average	Dependent Variable Standard Deviation	Number of Points
GEOA = 3.90 + 0.809 (ARITHA)	0.933	67.79	31.73	58.74	26.58	885
GEOA = 22.53 + 0.242 (OB24)	0.679	152.69	99.55	59.51	27.20	910
ARITHA = 0.04 + 1.153 (GEOA)	0.933	58.74	26.58	67.79	31.73	885
OB24 = -14.15 + 2.804 (GEOA)	0.679	59.51	27.20	152.69	92.55	910
EX24 = 33.20 + 1.152 (OB24)	0.841	152.06	100.35	208.35	126.02	838

[a]GEOA denotes annual geometric mean; ARITHA denotes annual arithmetic mean; OB24 denotes observed second-high 24-hour value; EX24 denotes expected second-high 24-hour value.

to convert background values. In this work, PM10 background values were computed using the following equations:

East of the Mississippi River:

$$\begin{aligned} \text{PM10 (annual)} &= 0.88 \times 0.61 \times \text{TSP (annual)} \\ &= 0.5368 \times \text{TSP (annual)} \end{aligned} \tag{2.1.1}$$

$$\begin{aligned} \text{PM10 (24-hour)} &= 0.90 \times 0.75 \times \text{TSP (24-hour)} \\ &= 0.6750 \times \text{TSP (24-hour)} \end{aligned} \tag{2.1.2}$$

West of the Mississippi River:

$$\begin{aligned} \text{PM10 (annual)} &= 0.77 \times 0.61 \times \text{TSP (annual)} \\ &= 0.4697 \times \text{TSP (annual)} \end{aligned} \tag{2.1.3}$$

$$\begin{aligned} \text{PM10 (24-hour)} &= 0.78 \times 0.75 \times \text{TSP (24-hour)} \\ &= 0.5850 \times \text{TSP (24-hour)} \end{aligned} \tag{2.1.4}$$

Finally, since different factors were used for converting background as opposed to other air quality values, the possibility arose that PM10 values might be below PM10 background. A check was made for this problem, and if it occurred the PM10 measure of air quality was obtained from the corresponding TSP measure using the same factor used to convert the corresponding background values, rather than 0.46.

The consistency between air quality measures and background values undoubtedly had no effect on the projection of future nonattainment, since if defaults were used due to inconsistencies with background values, the air quality values were quite low and would not have led to nonattainment problems for any reasonable growth rates. Since all four measures of air quality were required for the subsequent benefits analysis, however, it was important to maintain consistency even in these cases.

2.2 CONTROL OPTIONS

As described in Sec. 6.2.2 of Ref. 1, chemical stabilization, a control method generally used to control emissions from roads and storage piles, was originally listed in the options file as a control method for certain industrial-process fugitive sources. This assignment was felt to be inappropriate for some of these sources, and chemical stabilization was not retained as a control option in these cases during the present work. Chemical stabilization was kept as an option where appropriate.

2.3 OTHER

Population growth rates developed by Mathtech and used by them in the analysis of benefits were used in this work in place of growth rates originally developed by Energy and Environmental Analysis, Inc. (EEA).

In this work, capital costs were calculated for controlling unpaved plant roads through paving. In the previous work, these capital costs had been calculated as zero.

3 PROJECTION OF FUTURE NONATTAINMENT

In the current system, the projection of air quality is carried out using individual-source coupling coefficients together with corresponding projected individual-source emission rates. The methodology for the projection of emission rates is the same as that used previously except that new-source control levels are now determined using a more detailed, SCC-specific algorithm rather than using a single generic efficiency. The computation of coupling coefficients is also the same as before, with a minor modification in the case of area sources.

In the present study, coupling coefficients were computed for all sources, including the "other" area source category, so that air quality projections and other computations involved in the report writers could be made in a consistent manner. Air quality projections were made for all four measures of air quality, instead of just those required for comparison with standards. This allowed the direct use of the results in the computation of benefits, without further processing. In addition, projections were made for all years in the analysis period. This eliminated the need for the ambiguous concepts of "binding year" and "binding standard" and also permitted the benefits computation to proceed without further processing of the results.

Section 3.1 discusses the emission projection methodology, and Section 3.2 reviews the computation and use of rollback coupling coefficients.

3.1 PROJECTION OF FUTURE EMISSIONS

3.1.1 Review of General Methodology

The equations used to estimate emissions from a given source for any specified future year are the same as those derived and discussed in Section 3.1 of Ref. 1. A summary of those equations is provided below.

For point sources, the controlled emission rate for either TSP or PM10 in year t is given by:

$$Q_p^c(\eta_o,\eta_n,\eta;t) = Q_p^c(0) \cdot f(\eta_o,\eta_n,\eta;t) \tag{3.1.1}$$

In this equation, $Q_p^c(0)$ = the corresponding controlled emission rate in the base year (i.e., the year associated with the inventory). The projection factor f is given by:

$$f(\eta_o,\eta_n,\eta;t) = f_c(\eta_o,\eta;t) + f_n(\eta_o,\eta_n;t) \tag{3.1.2}$$

with

$$f_c(\eta_o,\eta;t) = (1 - K + bL + aM) \left[\frac{100 - \eta}{100 - \eta_o}\right] \tag{3.1.3}$$

$$f_n(\eta_o,\eta_n;t) = [(1 - b)L + (1 - a)M] \left[\frac{100 - \eta_n}{100 - \eta_o}\right] \tag{3.1.4}$$

where:

η_o = the base inventory control efficiency (percent),

η_n = the control efficiency associated with new-source control,

η = the control efficiency associated with whatever control device is in place in year t, and

a and b = the fraction of new growth sources and replacement sources, respectively, coming on-line at current control levels rather than at new-source control levels.

The quantities K, L, M depend on the projection year t and are computed as follows:

$$\text{Define } G = (1 + g)^{\Delta t} - 1 \tag{3.1.5}$$

$$\text{and} \quad R = 1 - (1 - r)^{\Delta t} \tag{3.1.6}$$

where:

g = the growth rate (fraction per year),

r = the replacement rate (fraction per year), and

Δt = the difference between the projection year t and the base year.

Then,

$$\begin{aligned} &K = R \text{ if } G \geq -R, \text{ and } K = |G| \text{ if } -R > G \\ &L = K \text{ if } G \geq 0, \text{ and } L = K-|G| \text{ if } 0 > G \\ &M = G \text{ if } G \geq 0, \text{ and } M = 0 \text{ if } 0 > G \end{aligned} \tag{3.1.7}$$

The part of the controlled emissions associated with new source controls, $Q_p^c(0)\cdot f_n$, is assumed to be unavailable for the development of a control strategy. The part of the controlled emissions associated with base-year or current controls, $Q_p^c(0)\cdot f_c$, is assumed to be available for further control.

In any given future year, for a point source, the emission reductions associated with new-source controls and with the imposition of additional control during the development of a strategy may be computed from

$$\Delta Q_n^c(\eta_o,\eta_n;t) = Q_p^c(0)\cdot[(1 - b)L + (1 - a)M] \left[\frac{\eta_n - \eta_o}{100 - \eta_o}\right] \tag{3.1.8}$$

and

$$\Delta Q_p^c(\eta_o,\eta;t) = Q_p^c(0)\cdot(1 - K + bL + aM)\left[\frac{\eta - \eta_o}{100 - \eta_o}\right], \tag{3.1.9}$$

respectively.

For area sources, the emission rate in year t is given by

$$Q_a^c(\eta_o,\eta;t) = Q_a^c(0)\cdot[1 + \gamma(N - 1)]\left[\frac{100 - \eta}{100 - \eta_o}\right] \tag{3.1.10}$$

where γ denotes the fraction of the area source that is assumed to grow at the population growth rate g_{pop}, and N is given by

$$N(t) = (1 + g_{pop})^{\Delta t} \tag{3.1.11}$$

Emission reductions in year t associated with the control option of efficiency η are given by

$$\Delta Q_a^c(\eta_o,\eta;t) = Q_a^c(0)\cdot[1 + \gamma(N - 1)]\left[\frac{\eta - \eta_o}{100 - \eta_o}\right] \tag{3.1.12}$$

No new-source control was assumed for area sources.

Only two categories of area sources were used in the present work, as opposed to three in the previous study. The two categories were (1) municipal paved roads and (2) other (everything else); the municipal unpaved road category used previously having been combined with the "other" category. Municipal paved roads was the only area source category for which a control option was available.

3.1.2 New-Source Control Methodology

The previous work had only a single Standard Industrial Classification (SIC)-dependent level of control available for any given new source. After that work had been completed, the question arose as to how many counties would be in attainment in the absence of a control strategy if the level of new-source control (NSC) were changed. To answer this question, four levels of NSC were considered in this work:

- Level 0 - The base year controls in the inventory,
- Level 1 - Controls currently required by new-source performance standards (NSPS) for particulates,
- Level 2 - Controls available within the model itself for use on existing sources during strategy development supplemented by estimates of reasonably available control technology (RACT), and
- Level 3 - Controls based on estimates of lowest achievable emissions rate (LAER).

The analysis system can be run with any of the four levels specified as the most stringent level of new source control. For a scenario specifying the most stringent level as MAXLEV, the NSC summary report (Box R9 in Fig. 1.1) provides the number of nonattainment counties under each level of NSC less than or equal to MAXLEV by region, section, and nation.

SCC-Specific TSP New-Source Control Efficiencies. TSP control efficiencies for Level 1 were based on information available in EPA's NSPS Cost-Effectiveness File, which summarizes the cost and control information presented in the background information documents (BIDs). Sources regulated at a particular level were identified by eight-digit source classification codes (SCCs) so that they could be matched to sources in the inventory. (Nonstandard two-digit SCC codes were used to identify nontraditional sources, e.g., plant roads and storage piles.)

TSP efficiencies for Level 2 came from two sources: the control options file (Box 4.2 in Fig. 1.1) and Ref. 2. If more than one option was available in the control options file, the most stringent option was chosen as the Level 2 NSC option. Inclusion of the strategy control options as NSC's ensures that the growth and replacement associated with a source will never be less stringently controlled than the controllable fraction of that source as long as Level 2 or Level 3 NSCs are being applied, thus correcting one of the potential problems with the previous system as noted in Sections 3.1.1 and 6.2.1 of Ref. 1. These strategy controls were supplemented by estimates of RACT from Ref. 2, increasing the number of SCCs for which specific NSC estimates were available. The more efficient TSP efficiency was chosen as the Level 2 new-source efficiency if values were available from both sources for a particular SCC.

Two sources of data, Refs. 2 and 3, were also used for estimating Level 3 TSP efficiencies. The data was handled in the same way as the Level 2 data.

Efficiencies were not available for each level for each SCC. For example, the strategy control file has information for SCCs for which no NSPS has been promulgated.

SCC-Specific PM10 New-Source Control Efficiencies. All the data sources noted above provided a TSP control efficiency and a specification of the control device. To estimate PM10 control efficiencies, a program (CRAIG9) using procedures similar to those described in Section 2.2.1 of Ref. 1 was developed. This procedure calculated the PM10 control efficiency corresponding to a given TSP efficiency for a particular type of source (SCC) and control device. The penetration functions, uncontrolled particle size distributions, and defaults were the same as those described in Ref. 1.

Level 3 Default Efficiencies. Data were not available to develop SCC-specific efficiencies for each SCC in the inventory. At Level 3, it was desired to control the new source fraction associated with each source in the inventory as had been done in the previous work. A default TSP efficiency of 99.3% was chosen as the Level 3 new source efficiency for all sources for which SCC-specific efficiencies were unavailable. The value of 99.3% was chosen as the average of the LAER efficiencies greater than 98% in the BACT/LAER Clearinghouse (Ref. 3). The 98% cutoff was included to keep the low efficiencies associated with some nonstandard sources from affecting the average applied to the standard sources included in the inventory.

As discussed in *New Source Control Levels for PM10* in Section 3.1.1 of Ref. 1, more than one PM10 efficiency would be expected to correspond to the default TSP efficiency of 99.3%. Using procedures similar to those described in that subsection, a program (CRAIG10) was developed which calculated average SCC-specific PM10 control efficiencies for the following ranges of inventoried TSP efficiency, $\eta_{INV}(TSP)$:

$$99.3\% = \eta_{INV}(TSP)$$

$$99.2\% \le \eta_{INV}(TSP) \le 99.4\%$$

$$99.1\% \le \eta_{INV}(TSP) \le 99.5\%$$

$$99.0\% \le \eta_{INV}(TSP) \le 99.6\%$$

Averages were also calculated for each range of TSP efficiencies for combustion and noncombustion sources, defined, respectively, as sources with SCCs beginning with 1 or 2 and sources with SCCs beginning with a digit greater than or equal to 3.

Because two of the averages were calculated for a range of TSP efficiencies centered about 99.3%, the corresponding PM10 efficiency could exceed 99.3%, the TSP efficiency. To avoid having a PM10 efficiency exceed a TSP efficiency, the default file was structured to preclude such values being chosen when a default efficiency was needed.

Assigning the New-Source Control Efficiencies. Both TSP and PM10 control efficiencies were assigned to the new-source activity associated with each point source by the procedure summarized in Fig. 3.1. In the figure,

ETAT1, ETAP1 = NS control efficiency estimates for TSP, PM10,

ETAT(J), ETAP(J) = arrays holding SCC-specific estimates of NSC control efficiencies from CONTDEF file for J = 1, 2, 3, and

MAXLEV = The level of NSC to be estimated (0, 1, 2, 3).

When a default PM10 efficiency is needed by the procedure, SCC-specific values are used in preference to the default values for combustion and noncombustion sources. For a particular SCC or default category, the default is chosen from the narrowest TSP range for which at least one inventoried source was included in the average. The final check on the efficiencies (ETAT1 and ETAT2), to ensure that they do not exceed 99.99%, precludes problems involved with very small (effectively zero) controlled emissions in later programs.

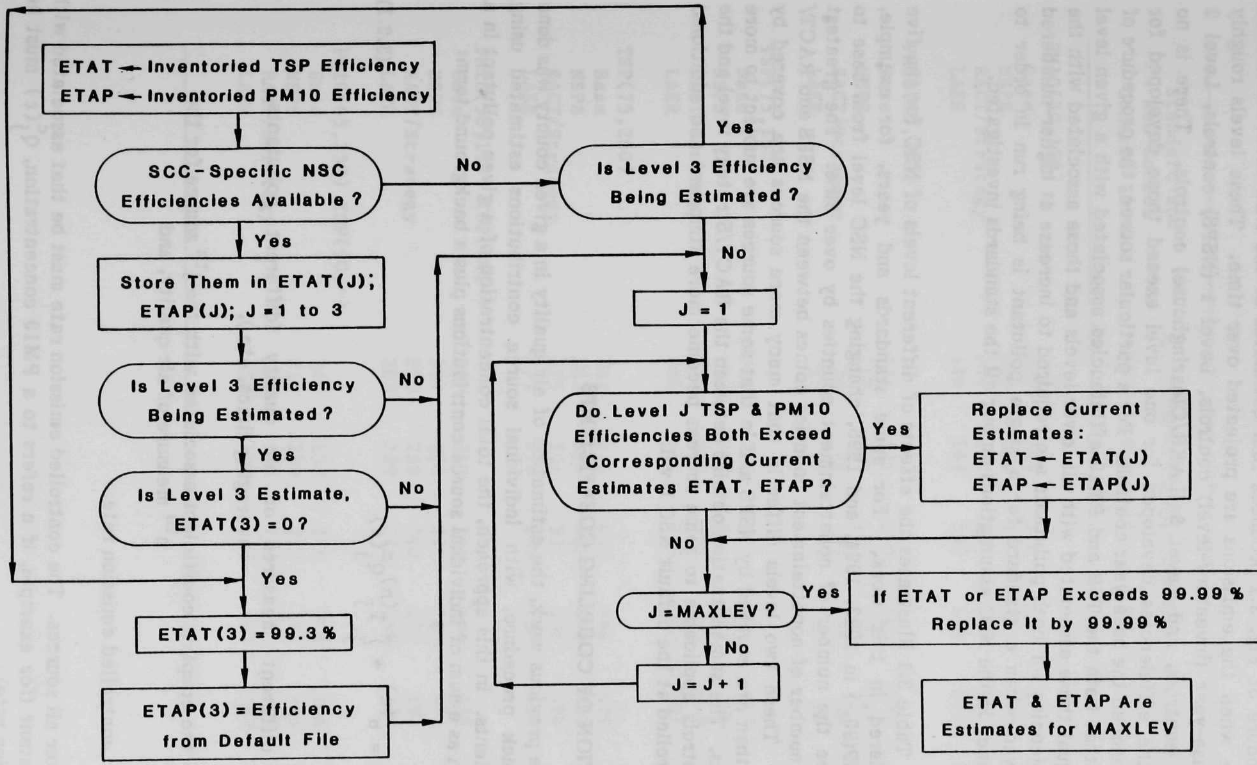

FIGURE 3.1 Estimation of New-Source Control Efficiency

The procedure of Fig. 3.1 produces four estimates of the NSC level associated with each source when the emissions are projected over time. These levels roughly correspond to base-year (inventory-level) controls, Level 1 (NSPS) controls, Level 2 (RACT/Strategy) controls, and Level 3 (LAER/Clearinghouse) controls. There is no guarantee that the efficiencies developed for one level exceed those developed for another level or exceed the base-year controls. For a particular source, the procedure of Fig. 3.1 ensures that both the TSP and PM10 efficiencies associated with a given level will exceed or equal those associated with all lower levels and those associated with the base year. Efficiencies for both pollutants are required to increase at higher-numbered control levels even when a standard for a single pollutant is being run in order to maintain consistency in the NSC assumptions among all the standards investigated.

Results. Table 3.1 illustrates the effects of different levels of NSC for the five standards considered in this work. For some standards and years, for example, PM10(50,150) TSP(90,-) in 1993, 1994, and 1995, changing the NSC level from base to LAER can reduce the number of nonattainment counties by over 50%. The greatest reduction in the number of nonattainment counties comes between the NSPS and RACT/ Strategy levels. These two levels differ in that many more sources are covered by RACT/Strategy than are covered by NSPS and in that some sources are subject to more stringent controls. The same situation obtains between the RACT/Strategy level and the LAER level: controls applicable to some sources become more stringent and additional sources are controlled at the default NSC level.

3.2 COMPUTATION OF COUPLING COEFFICIENTS

As in the previous work, the estimation of air quality in a given county was done using the rollback procedure, with individual source contributions estimated using coupling coefficients. In this approach, the total concentration of a given pollutant in a county is written as a sum of individual source contributions plus a background term:

$$\chi^{(n)}(t) = b^{(n)} + \sum_j T_j^{(n)} Q_j^c(t) \tag{3.2.1}$$

where:

(n) = different measures of air quality (different pollutants, averaging times, etc.),

$T_j^{(n)}$ = the coupling coefficient associated with the j^{th} source for the n^{th} measure of air quality, and

$Q_j^c(t)$ = controlled emission rate.

Summation is over all sources. The controlled emission rate must be that associated with the proper pollutant (for example, if n refers to a PM10 concentration, $Q_j^c(t)$ must be the PM10 emission rate).

TABLE 3.1 Nonattainment under Alternative New-Source Controls

Standard and New-Source Control Level	Number of Nonattainment Counties by Year						
	1989	1990	1991	1992	1993	1994	1995
PM10(50,150)							
Base	329	346	370	399	421	442	463
NSPS	288	300	319	347	365	383	402
RACT/Strategy	231	233	241	248	261	265	275
LAER	188	189	190	188	191	193	197
PM10(65,250)							
Base	128	135	149	161	172	184	190
NSPS	117	121	127	134	145	155	164
RACT/Strategy	74	77	83	88	96	100	109
LAER	55	55	56	58	60	63	66
TSP(75,150)							
Base	744	766	787	804	817	827	844
NSPS	688	708	728	742	756	768	782
RACT/Strategy	567	585	599	607	619	623	635
LAER	480	486	496	500	507	516	524
TSP(75,260)							
Base	387	414	431	446	470	496	517
NSPS	362	384	402	414	436	458	476
RACT/Strategy	325	331	331	336	339	345	349
LAER	275	279	279	281	284	287	285
PM10(50,150) TSP(90,-)							
Base	347	362	383	410	435	455	477
NSPS	307	321	337	363	382	399	416
RACT/Strategy	250	252	262	270	283	288	296
LAER	205	209	210	210	216	222	223
PM10(65,250) TSP(90,-)							
Base	248	257	270	286	296	304	325
NSPS	212	225	233	245	256	266	280
RACT/Strategy	165	166	173	181	188	191	198
LAER	138	142	143	145	149	157	158

The coupling coefficient is computed using base-year emission rates and measured air quality (Ref. 1, Section 3.2.1):

$$T_j^{(n)} = \frac{w_j}{\sum_k w_k Q_k^c(0)} \left(\chi^{(n)}(0) - b^{(n)}\right) \tag{3.2.2}$$

It is assumed in the current system that the background term $b^{(n)}$ is a constant, although the assumption of any specified time dependence could easily be incorporated. Four different choices for the weight factors w_j are available, as discussed in Ref. 1. The choice recommended in Section 6.2.2 of that report was used throughout the present study. For any given source, that procedure may be summarized as follows:

$$\text{Compute } F_j = \frac{g}{\pi}\left[\frac{T_j - T_a}{T_j}\right] V_j \tag{3.2.3}$$

where:

g = acceleration due to gravity = 9.80 m/s,

π = 3.14159...,

T_j = exit gas temperature (K), and

V_j = exit gas flow rate at temperature T_j (m^3/s).

$$\text{Compute } C_j = \begin{cases} 21 \cdot F_j^{3/4} m^2/s & \text{for } F_j < 55\ m^4/s^3 \\ 38 \cdot F_j^{3/5} m^2/s & \text{for } F_j \geq 55\ m^4/s^3 \end{cases} \tag{3.2.4}$$

$$\text{Compute } U^* = \text{MAX}\ (C_j/h_j,\ 2.5\ m/s) \tag{3.2.5}$$

where:

h_j = physical stack height (m), or 10m, whichever is greater.

$$\text{Compute } w_j = \frac{250\ U^*}{(U^* h_j + C_j)^2} \tag{3.2.6}$$

Once the coupling coefficients have been computed for each source in the inventory, the change in air quality in year t associated with imposition on a given source of some control option in place of base-year controls may be estimated from

$$\Delta\chi_j^{(n)}(t) = T_j^{(n)} \cdot \Delta Q_j^c(\eta_o, \eta; t) \tag{3.2.7}$$

As discussed in Section 3.1.2 of Ref. 1, evidence exists that reentrained road dust from paved roads has a limited effective range. In the previous work, the limited range of particulate matter from all categories of area source was simulated by defining an "effective fraction" for each category as that fraction of the total countywide emissions from the given category of emitters that directly affects the receptor being modeled. Only that fraction of the emissions was used in computing air quality effects, determining control strategies, and estimating control costs. In the present study, the emissions in each category were kept at the total countywide level, and the weight w_j for such sources was multiplied by the effective fraction defined in the previous work. The reason for adopting this new procedure was that the limited range of such effects is a physical phenomenon more clearly associated with the coupling coefficient concept than with emission rates, and there was some initial concern regarding the calculational consistency of the old procedure. As in the earlier study, only the effective fraction of the total municipal paved roads was considered in the estimation of control costs for such sources, on the assumption that only this much would be controlled in a realistic strategy. The study results are in fact unaffected by the adoption of this procedure instead of that used in the previous work.

4 CONTROL STRATEGY DEVELOPMENT

The development of a control strategy for each county considered in this study involved three steps: (1) identification of those counties that are projected to violate air quality standards unless additional emission controls are imposed, (2) compilation of available control options for sources in the projected nonattainment counties, and (3) actual development of an optimum control strategy for each such county. The methodology used to project future air quality has been described in Section 3, and the determination of compliance with standards in any specified year involved simply the comparison of the four projected measures of air quality with the corresponding standards. A violation was not considered to occur unless the projected measure of air quality exceeded the corresponding standard by at least 1.0 $\mu g/m^3$. In the present system, the actual number of operative standards may range from one to four, and the standards may be implemented in different years. In this study however, all standards in effect for a given scenario were assumed to commence in the first year of the study period.

A list of available control options was compiled and a control strategy was developed for each county projected to have a nonattainment problem. The selection of the set of control options is described in Section 4.1, and the control strategy algorithm is discussed in Section 4.2.

4.1 CONTROL OPTIONS

The procedure and data base used to prepare a list of available control options for each source in a given county were the same, with minor modifications, as used previously and described in Sections 2.3 and 4.2 of Ref. 1. The following is a list of the computer code modifications made for this study:

- Control costs were computed in first-quarter 1984 dollars instead of mid-1980 dollars. This change entailed multiplication by a factor of 1.125 of the capital and operating/maintenance costs computed using coefficients in the options file.

- Both TSP and PM10 cost-effectiveness caps were converted to first-quarter 1984 dollars to maintain consistency with the cost computations. In addition, the PM10 cost-effectiveness cap was set equal to the TSP cap divided by 0.46, rather than 0.55. This change maintains consistency with the use of the revised PM10/TSP ratio value in the development of the air quality data base. The actual values of the cost-effectiveness caps were

  TSP: $13,500/(T/yr)

  PM10: $29,250/(T/yr).

- As discussed in Ref. 1, the after-tax annualized cost (ATAC) of an option was used in the identification and elimination of dominated options, i.e., those that cost more but provide less control than some other option. Due to recent changes in U.S. tax laws, the formula by which ATAC was computed was changed to read:

$$\text{ATAC} = C(1 - D) \left[1 - \frac{T}{N}\left(\frac{(1 + B)^N - 1}{B(1 + B)^N}\right)\right]\left[\frac{R(1 + R)^N}{(1 + R)^N - 1}\right] + (1 - T)M \tag{4.1.1}$$

where:

C = capital cost,

M = operating/maintenance cost,

N = equipment lifetime (years),

R = real interest rate,

I = inflation rate,

B = I + R + I · R = nominal interest rate,

T = tax rate, and

D = investment tax credit rate.

In addition, as discussed in Section 2, certain inappropriate control options were deleted from the options file prior to its use in this study.

In the previous study, the set of control options available in a given nonattainment county might not have been sufficient to ensure that the county could reach attainment throughout the analysis period. In such cases, a more approximate method was used to estimate the additional costs of the necessary controls (see Section 6.7 of Ref. 1 and Section 6.1 of this report). It was sometimes difficult to clearly identify the reasons why attainment was not reached, but one possible reason was that the list of control options was incomplete and control options were not available for all sources during the strategy development. In order to investigate this possibility, generic control efficiencies were defined and made available for many sources that would otherwise have gone uncontrolled. This procedure was used only as part of the sensitivity analyses discussed in Section 6.2 and was not used for the baseline calculations. This procedure is now available as an option that may be selected by the user at runtime. (See Section 6.2 for a detailed discussion of the procedure.)

4.2 CONTROL STRATEGY ALGORITHM

Ideally, the control strategy developed for a given county should be that for which the overall cost of control is a minimum. The determination of such a least-cost control strategy may be accomplished in principle by a linear programming approach. In this application, however, linear programming requires too much computer time to be practical and an alternative method must be adopted. The previous system utilized a heuristic, stepwise algorithm (the Incremental Cost-Effectiveness, or ICE, algorithm) based on the idea that at each step the most cost-effective control option available should be the next one implemented. In this method, controls were implemented either until the required concentration reduction was achieved or until each source was controlled to the maximum extent allowed by the set of available control options. In some cases, this algorithm was found to give a solution that could be significantly improved, in the sense of achieving a lower overall cost without allowing a violation of air quality standards, by a brief visual inspection (Ref. 1, Section 4.3.3). This means that the ICE algorithm tended to overestimate overall control costs. A new algorithm (the Maximum Cost Reduction, or MCR, algorithm) was developed in response to this assessment.

The MCR algorithm consists of the following steps:

1. For each source, implement the most stringent available control option (the option that produces the greatest emission reduction). If this does not result in attainment for all operative air quality standards, the county in question is intractable; the set of options assumed to be available is insufficient to reach attainment.

2. Determine the set of sources that have available at least one less-stringent control option. This is the set of sources for which at least one level of relaxation of control is possible. Examine the next-less-stringent control option for each source in this set and determine which of these options, if any, could replace the current (more stringent) option without causing a violation of air quality standards. Each such possible substitution represents an allowable relaxation. Relaxations involving more than one step down in stringency in the list of available options for a given source are not considered. If no allowable relaxation can be found, the current set of controls is the solution.

3. If one or more allowable relaxations exist, determine the one that, if implemented, would result in the greatest overall cost reduction (the MCR relaxation). Implement this relaxation and return to Step 2.

Although the MCR algorithm is not guaranteed always to yield the true least-cost solution, it has been found to be superior to the ICE algorithm in all examples considered, in that the overall cost of control is always less than or equal to that produced by the ICE algorithm. No mathematical proof of superiority in all possible cases is available, but no counterexample has been found. The final solution consists of a list of sources to be controlled together with a single option to be implemented for each.

A multiyear strategy was developed for each county by using the MCR algorithm on a year-by-year basis. Figure 4.1 is a schematic flow diagram of the multiyear algorithm. If the first and final years are the same, the algorithm reduces to the basic MCR algorithm described above. In this study, it was assumed that once a control option was implemented as part of the solution strategy for some year, it could not be removed in a later year except to be replaced by a more stringent option. This assumption amounted to a restriction on the relaxations that could be considered for that source as part of the determination of the MCR relaxation. The assumption is appropriate for options involving the purchase or construction and operation of expensive pieces of machinery, but the multiyear MCR algorithm does not depend on such an assumption for proper operation. A source could be controlled more than once during the analysis period.

In order to use the MCR algorithm, methods must be available for the computation of (1) total pollutant concentration for any specified set of control options and for the specific measures of air quality of interest, in order to determine if standards are met; (2) changes in pollutant concentrations associated with any relaxation being considered as an MCR candidate; and (3) cost reductions associated with MCR candidate relaxations. In this study, total concentrations and changes due to imposition or relaxation of individual source controls were computed using the formulas summarized in Sections 3.1 and 3.2. The changes in individual source TSP and PM10 controlled emission rates associated with relaxation from (say) Option 2 to Option 1 in year t were calculated from:

$$\Delta Q^c(t) = \Delta Q^c(\eta_o, \eta_1; t) - \Delta Q^c(\eta_o, \eta_2; t) \tag{4.2.1}$$

where each term on the right-hand side was computed using Eq. 3.1.9 for a point source or Eq. 3.1.12 for an area source. Computation of cost reductions was done with the following algorithm:

- If the candidate relaxation would lead back to base-year controls, the associated cost reduction was computed from:

$$\Delta C(t) = \phi(t) \cdot [OM + CAP \cdot CRF(T)] \tag{4.2.2}$$

where t is the year for which the strategy is being developed; $\phi(t)$, the "controllable fraction" of each source, is given by

$$\phi(t) = 1 - K(t) + bL(t) + aM(t) \tag{4.2.3}$$

where:

K, L, and M = definitions in Section 3.1;

T = equipment lifetime, taken to be 15 years in this study,

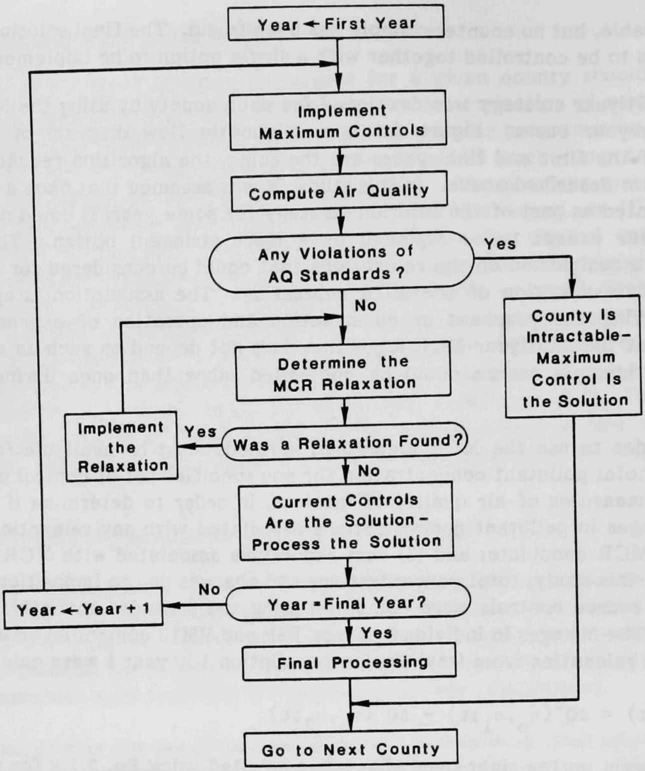

FIGURE 4.1 Multiyear Control Strategy Algorithm

OM and CAP = operating/maintenance and capital costs for the control option, and

CRF(N) = capital recovery factor for N years:

$$CRF(N) = \frac{R(1 + R)^N}{(1 + R)^N - 1} \tag{4.2.4}$$

where R = real interest rate.

- If the candidate relaxation would lead to an option not previously implemented, the associated cost reduction was calculated from:

$$\Delta C(t) = \phi(t) \cdot \{[OM_k + CAP_k \cdot CRF(T)] - [OM_{k-1} + CAP_{k-1} \cdot CFR(T)]\} \tag{4.2.5}$$

where the relaxation is assumed to be from Option k to Option k-1.

- If the option to which the candidate relaxation would lead has already been imposed in a previous year, the associated cost reduction was calculated from:

$$\Delta C(t) = \Bigg\{ \phi(t) \cdot \left[OM_k + CAP_k \cdot CRF(T) \right] - \left[OM_{k-1} + CAP_{k-1} \cdot CRF(T) \right] + CAP_{k-1} \cdot CRF(T) \cdot \left[\frac{CRF(T)}{CRF(T + \Delta t)} - f_c \right] \Bigg\} \qquad (4.2.6)$$

where:

Δt = (current year) - (year in which option k-1 was imposed), and

f_c = fraction of the capital cost of Option k-1 that is assumed to have been spent on equipment, such as ductwork, that can be used as part of the Option k system.

In this study, f_c was taken to be 0.5.

5 REPORTS

The various reports produced by the current analysis system provide the following information:

- *Emission Summary Report* (R10 in Fig. 3.1): for all years in the analysis period: TSP and PM10 projected emissions by source category, prior to the imposition of control strategies.

- *New Source Control Summary Report* (R9): for all years in the analysis period: (1) number of counties projected to not attain air quality standards, and the number of initial nonattainment counties, for different levels of new-source control; and (2) associated TSP and PM10 emission reductions.

- *National Cost Report* (R6): for all years in the analysis period: (1) costs of new emission controls (present values, before-tax annualized costs, new capital costs, and new operating/maintenance costs), (2) emission reductions, and (3) solid waste production.

  All three are summed over all SICs as well as for a specified set of major SICs; the major SICs include a standard set (4911, 3312, 1422, 1429, 1442, 2041, 2621, 2951, 3241, 3274, 3281, 3295, 3321, 3331, 3332, 3334, 4961, 5153) and any other SIC contributing 3% or more of the national total discounted present value.

  Also given are national total discounted present value (DPV) of new controls and contributions to each item above from nontraditional fugitive point sources.

- *Sectional and Regional Cost Report* (R7): same as in National Cost Report except that no results are given for specific SICs. The states in the sections and regions were defined as in Ref. 1, Appendix B. For convenience, that appendix has been reproduced in Appendix C of this report.

- *B-Scenario Report* (R8): yearly before-tax annualized costs and total discounted present values associated with the reduction of residual nonattainment for the entire analysis period, on a county-by-county basis. See Section 6.1 for a discussion.

The number of counties that did not come into attainment under the strategy (the residual nonattainment counties) was not available in a standard report. The number of residual nonattainment counties was determined by a program that read the Future County Status File (No. 99.1 in Fig. 1.1).

Appendix B presents summaries of data from these reports. Tables B.1-B.6 present TSP and PM10 emission projections for the base year and each analysis year for the nation and by region and section. Table B.7 presents national DPV and BTAC costs for both the baseline control strategy and reduction of residual nonattainment. National DPV costs and emission reductions achieved by the application of the control strategy are presented in Tables B.8-B.11 by source type and by the major SICs. Tables B.12 and B.13 present regional and sectional DPV costs and initial and residual numbers of nonattainment counties. Table B.14 presents national costs by year, including reduction of residual nonattainment.

5.1 EMISSION AND NEW-SOURCE CONTROLS SUMMARY REPORTS

These two reports summarize the projected TSP and PM10 emissions and provide information on the emission reductions associated with the different new-source control scenarios examined in this study.

The Emission Summary Report provides national, regional, and sectional TSP and PM10 emissions for the base year and each year in the analysis period. These emissions are totaled for point sources (Q_P), nontraditional fugitive sources (Q_{NTF}), area sources (Q_A), effective area sources (Q_{AEFF}) (defined as α [paved road sources] + β [other sources], where α and β denote the effective fractions for paved roads and other area sources, respectively); total ($Q_T = Q_P + Q_{NTF} + Q_A$) and effective total ($Q_{TEFF} = Q_P + Q_{NFT} + Q_{AEFF}$) values are also given. These results are computed by appropriate summation of the projected emissions for each source in the inventory and require no further explanation.

The New-Source Control Summary Report provides, for each year in the analysis period and on national, regional, and sectional levels, the number of counties projected to be in nonattainment (by standard and in total). These results are provided for each different new-source control scenario used in the study and are computed from a comparison of air quality values projected for each such NSC scenario with assumed ambient air quality standards; thus, one such report is produced per ambient air quality standard scenario. Also given are the associated reductions in TSP and PM10 emissions, computed from Eq. 3.1.8 and summed over sources, as appropriate.

5.2 NATIONAL, REGIONAL, AND SECTIONAL COST REPORTS

Several computations that differ in detail from those in the previous study and that require explanation here take place in producing these reports. Since the new analysis system develops a multiyear control strategy, thereby allowing controls for different sources to be implemented in different years and also allowing the same source to be controlled in more than one year, the computation of the before-tax annualized cost (BTAC) and the corresponding DPV was more complicated than in the previous system. In addition, in order to facilitate proper comparison of control costs with the dollar value of benefits computed from air quality improvements over the analysis period, it was necessary to truncate costs at the end of the analysis period, even though the control equipment lifetime was assumed to be such that controls would remain in place beyond that point. The following procedure was used to compute yearly annualized costs:

1. If a source is controlled only once during the analysis period (in year t_1, for example), the associated annualized cost, neglecting the effective fraction $\phi(t)$ (see Eq. 4.2.3), is given by:

$$AC = OM + CAP \cdot CRF(T) \tag{5.2.1}$$

The effective before-tax annualized cost in year t is:

$$BTAC(t) = \begin{cases} 0 \text{ if } t < t_1 \\ \phi(t) \cdot AC \text{ if } t_1 \le t \end{cases} \tag{5.2.2}$$

2. If a source is controlled twice during the analysis period (in years t_1 and t_2, with $\Delta t = t_2 - t_1 > 0$), define AC_1 and AC_2 by:

$$AC_1 = OM_1 + CAP_1 \cdot CRF(\Delta t) \tag{5.2.3}$$
$$+ f_c \cdot CAP_1 \cdot [CRF(T + \Delta t) - CRF(\Delta t)]$$

$$AC_2 = OM_2 + CAP_2 \cdot CRF(T) \tag{5.2.4}$$
$$+ f_c \cdot CAP_1 \cdot [CRF(T+\Delta t) - CRF(T)]$$

BTAC(t) is then given by:

$$BTAC(t) = \phi(t) \cdot \begin{cases} AC_1 \text{ if } t_1 \le t < t_2 \\ AC_2 \text{ if } t_2 \le t \end{cases} \tag{5.2.5}$$

Given the BTAC(t) values for each year t in the analysis period, the discounted present value associated with each is given by:

$$DPV(t) = \frac{BTAC(t)}{(1 + I)^{t-1983}} \tag{5.2.6}$$

and the total cumulative present value by:

$$DPV_{TOT} = \sum_t DPV(t). \tag{5.2.7}$$

Two control options at most were available for any given source in the current study, and the expressions given above cover all possible cases.

Yearly emission reductions are given by a summation over all relevant sources of quantities $\Delta Q^c(t)$ computed from Eqs. 3.1.9 and 3.1.12. Solid waste production in any given year is defined as the total TSP emission reduction from point sources, excluding the nontraditional fugitive point sources, and is computed by suitable summation of the TSP emission reduction values.

6 ADDITIONAL ANALYSES

In addition to the main analysis described in the previous sections, two additional analyses were conducted to address the issues of reduction of residual nonattainment and model sensitivity to parameter values and other assumptions. These analyses are discussed in the following sections.

6.1 REDUCTION OF RESIDUAL NONATTAINMENT

For a variety of reasons, in some counties the imposition of a control strategy did not result in attainment of air quality standards throughout the entire analysis period. Possible reasons include (1) predominance of large uncontrollable sources, especially in the "other" area source category, that either are real (e.g., rural fugitive dust areas) or are an artifact due to bad emission data; (2) lack of sufficiently stringent and suitable controls in the control option list for specific important inventory sources; and (3) utilization of rollback as an air quality modeling tool. In such a county, the set of controls assumed to be available to the corresponding sources is insufficient, and the strategy algorithm results in the imposition of maximum controls. The procedure adopted in this study to estimate the costs of additional controls needed to ensure attainment in these counties differs from that used in the previous work and is described in this section.

Two quantities, termed marginal and average multipliers ($\mu_m^{(n)}$ and $\mu_a^{(n)}$ respectively), are defined as follows:

- In any given county, $\mu_m^{(n)} = \text{MAX}\left[\dfrac{\Delta\text{BTAC}}{\Delta\chi^{(n)}}\right]$ (6.1.1)

  where the maximum is over all allowable source/control option combinations, and for a given combination:

  ΔBTAC = incremental increase in BTAC

  $\Delta\chi^{(n)}$ = incremental decrease in the n^{th} measure of air quality.

  Note that $\mu_m^{(n)}$ does not depend on the year in which the particular option associated with the maximum value is implemented. Essentially, $\mu_m^{(n)}$ represents the cost per unit air quality for the worst (most cost-ineffective) option available in the county.

- In any given county, $\mu_a^{(n)}(t) = \dfrac{\sum_j \phi_j(t) \cdot \text{BTAC}_j}{\sum_j \phi_j(t) \cdot \Delta\chi_j^{(n)}}$ (6.1.2)

  where the summations are taken over all options implemented under maximum control conditions; in other words, for each source having at least one option available, the most stringent is used. $BTAC_j$ and $\Delta\chi_j^{(n)}$ are the associated before-tax annualized cost and decrease in the n^{th} measure of air quality. Note that $\mu_a^{(n)}$ does depend on the year in which it is evaluated, because the effective fractions $\phi_j(t)$ change with time and do not cancel in Eq. 6.1.2. Essentially, $\mu_a^{(n)}(t)$ represents for the n^{th} measure of air quality the average cost of control per unit air quality in year t under maximum control conditions.

The current analysis system has the capability to estimate the cost of removing residual nonattainment in a given county by the following procedure:

1. In any given year t, compute

$$\Delta C^{(n)}(t) = \begin{cases} 0 \text{ if } \chi^{(n)}(t) \le \chi'^{(n)}(t), \text{ and} \\ \left[\chi^{(n)}(t) - \chi'^{(n)}(t)\right] \{\mu_m^{(n)} w(t) + \mu_a^{(n)}(t)\ [1 - w(t)]\} \\ \text{if } \chi^{(n)}(t) > \chi'^{(n)}(t) \end{cases} \tag{6.1.3}$$

where:

$\chi^{(n)}(t)$ = projected value of the n^{th} measure of air quality in year t, under maximum control conditions,

$\chi'^{(n)}(t) = \underset{i=1 \text{ to } t-1}{\text{MAX}} \left[\chi^{(n)}(i)\right]$, which is the maximum of all the t - 1 previous values of $\chi^{(n)}(t)$, or χ_{STD} + 1.0 $\mu g/m^3$,

$w(t)$ = ratio of total emissions from sources controlled by the strategy to the total emissions from all sources (either TSP or PM10 emissions, depending on the particular measure of air quality), in year t, and,

$\Delta C^{(n)}(t)$ = incremental increase in year t in the before-tax annualized cost associated with controls required to attain the ambient standard associated with the n^{th} measure of air quality.

The value of $\Delta C^{(n)}(t)$ is computed from the marginal and average multipliers by associating the marginal multiplier with sources that have already been controlled, and the average multiplier with sources not controlled by the strategy, the proportion being taken equal to the appropriate ratio of emissions.

2. Compute $\Delta BTAC(t) = MAX[\Delta C^{(n)}(t)]$ (6.1.4)

i.e., select the highest increment for year t, since all standards are to be attained in that year.

3. Compute the total before-tax annualized B-scenario cost in year t from

$$BTAC(t) = \sum_{i=1}^{t} \Delta BTAC\ (i) \tag{6.1.5}$$

4. Compute the discounted present value and cumulative discounted present value of such controls from the BTAC(t) values using Eqs. 5.2.6 and 5.2.7.

The original intention in the present study was to compute the costs of reducing residual nonattainment (the B-scenario costs) using the algorithm just described. As in the previous study, however, it was discovered that the marginal multipliers were so large that the computed B-scenario costs were quite unreasonable. The computer code was then modified so that only the average multipliers were used; this modification is equivalent to setting w(t) equal to zero for all t. Table 6.1 is a comparison of the B-scenario costs with and without marginal multipliers for the state of Alabama only and for a particular set of PM10 standards. The use of marginal multipliers, even in the manner outlined above, results in an increase in B-scenario costs by a factor of nearly 1400! Given the data uncertainties and the other uncertainties in the analysis system, especially the use of rollback, the use of the marginal multipliers does not seem justified.

The algorithm used in this study, even without the use of marginal multipliers, differed from that used previously (Ref. 1, Section 6.1) in that the B-scenario costs associated with a particular county were estimated using results specific to that county. In the previous study, only a national average multiplier was used.

6.2 SENSITIVITY ANALYSES

A number of sensitivity analyses were conducted to examine the effect of various parameters on costs and nonattainment status.

6.2.1 Growth and Effective Fraction Parameters

Table 6.2 summarizes the results obtained by varying the growth parameter b for point sources, the growth parameter γ for "other" area sources, and the effective fraction parameters α and β for area sources. All sensitivity runs were made for the PM10(50,150) standard. As might be expected, the results were quite sensitive to the choice of growth parameters. The first three lines in the table show the effect of increasing the fraction b of replacement sources subject to current rather than new-source controls. A larger value of b corresponds to larger projected emissions and, as

TABLE 6.1 Test Case B-Scenario Costs[a]

	With Marginal Multipliers		Without Marginal Multipliers	
Year	DPV[b]	BTAC[c]	DPV	BTAC
1989	20,800	36,900	14	26
1990	23,000	44,700	17	32
1991	24,800	53,100	18	39
1992	26,400	62,200	19	45
1993	27,500	71,400	20	52
1994	28,500	81,300	21	59
1995	29,300	92,000	21	67
Total	180,000	---	131	--

[a]State of Alabama only; costs given in (10^6 first-quarter 1984 dollars).

[b]DPV = discounted present value.

[c]BTAC = before-tax annualized cost.

TABLE 6.2 Effects of Growth and Effective Fraction Parameters[a]

	Points		Areas			Number of Nonattainment Counties		National 1982 DPV Costs ($\$10^6$)[b,c]
Line	a	b	α	β	γ	1989 Initial	1995 Residual	
1	0	0	0.01	0.01	0	160	65	832
2[d]	0	0.5	0.01	0.01	0	188	87	1015
3	0	1.0	0.01	0.01	0	232	117	1168
4	0	0.5	1.0	1.0	1.0	223	171	3936

[a]Run for the standard PM10(50,150).

[b]Costs are in first-quarter 1984 dollars.

[c]DPV is total of seven yearly values for 1989-1995.

[d]Parameters used in base analysis runs.

expected, the number of nonattainment counties and the national costs increase with b. The last line in Table 6.2 shows the effect of increasing the effective fractions for paved roads and area sources. To accentuate the effect, all area sources have been allowed to grow at the population growth rates ($\gamma = 1$), not just the paved road emissions as under the base conditions ($\gamma = 0$).

Nonattainment and costs with all area sources effective and growing ($\alpha = \beta = \gamma = 1.0$) are quite large compared to the costs in the other cases. In this case, the "other" area sources are all effective and all grow. These "other" area sources are not controlled by the strategy. Therefore, point sources must be controlled to offset the emissions from these area sources, and costs rise significantly.

The importance of the uncontrollable area sources is shown by comparing lines 2 and 4 in Table 6.2. In line 4, all area sources grow and all their emissions are assumed to affect the receptor of interest, while in line 2, only municipal paved roads grow and only 1% of the area source emissions are assumed to affect the receptor of interest. With the importance and growth of area sources accentuated (line 4), both the fraction and absolute number of the initial nonattainment counties that reach attainment are substantially reduced while national DPV costs increase by a factor of approximately four. These results clearly indicate that the choice of the parameters, particularly those associated with area sources, has an important effect on the final nonattainment status and the final costs.

6.2.2 Generic Control Options

As noted in Section 4.1, one reason for residual nonattainment after application of the control strategy may have been the lack of control options available for application to particular sources during the development of the control strategy. To test this supposition, a set of generic control efficiencies was developed for external combustion and process sources. During a sensitivity run of the model, these generic efficiencies were applied to external combustion and process sources for which there were no control options available in the cost and control file (No. 4.2 in Fig. 1.1). Generic efficiencies were not applied to sources for which an option was available in the cost and control file but that was not applied to the source because either it was less efficient than current controls or its cost-effectiveness (CE) ratio(s) exceeded the CE cap(s). No controls, either generic or from the cost and control file, were applied to solid waste disposal sources, i.e., those with SCCs of the form 5XXXXXXX.

Table 6.3 presents the generic efficiencies applied to sources in different SCC ranges. These efficiencies are averages over the efficiencies in the cost and control file; the table also indicates the basis for the average efficiency used. When more than one efficiency was available for a particular SCC in the cost and control file, only the highest value was included in the average. In addition, efficiencies which seemed unusually low in comparison to others in the SCC range being considered were eliminated from the average. For SCC ranges for which both process and fugitive controls were available in the cost and control file, the lower fugitive efficiencies were dropped from the average. These generic control efficiencies are not intended to be more than rough estimates. In essence, they extend the application of the data in the cost and control file to SCCs for which the file was not developed.

TABLE 6.3 Generic Control Efficiencies

EPA Source Classification Code (SIC)	Control Efficiency (%) TSP	PM10	Basis of Assignment
101001-101003	99.7	92.1	Coal-fired boilers
101004-101999	90.0	89.9	Residual-oil-fired boilers
102001-102003	99.7	92.1	Coal-fired boilers
102004-102999	90.0	89.9	Residual-oil-fired boilers
103001-103003	99.7	92.1	Coal-fired boilers
103004-103999	90.0	89.9	Residual-oil-fired boilers
301000-303999	98.9	98.6	Chemical manufacturing, food and agriculture, and primary metal sources[a]
304000-304999	98.5	98.2	Secondary metals sources
305001-305018	98.9	97.5	Mineral products, including coal cleaning
305019-305020	93.9	93.5	Mining[b]
305021-305888	90.0	90.0	Mostly mining and bulk minerals[c]
390001-390999	90.0	89.9	Residual-oil-fired boilers[d]
All Other 3__	98.9	98.1	All process sources

[a]Chemical manufacturing and food and agriculture had $\bar{\eta}_{TSP} = 99.0$, $\bar{\eta}_{PM10} = 98.6$; primary metals had $\bar{\eta}_{TSP} = 98.8$, $\bar{\eta}_{PM10} = 98.6$.

[b]Nonfugitive controls available in cost and control file.

[c]Only fugitive controls available in cost and control file.

[d]Arbitrary assignment; no data in cost and control file.

TABLE 6.4 Sensitivity of Nonattainment and Costs to Key Parameters[a]

Line	Generic Control Efficiencies?	Coupling Coefficient Weighting Factor (w_j)	Growth Rates for SICs 33,49	Number of Nonattainment Counties: 1989 Initial	Number of Nonattainment Counties: 1995 Residual	1983 National DPV ($\$10^6$)[b,d]
1	Yes	Base	Base	188	54	N/A
2	No	1	Base	156	73	828
3	No	Base	EPA	176	70	763
4[d]	No	Base	Base	188	87	1015

[a]All sensitivity runs made with base growth parameters (a=0, b=0.5, α=0.01, β=0.01, γ=0.0) for the PM10(50,150) standard.

[b]Values are totals of the seven yearly values for 1989-1995.

[c]Units are first-quarter 1984 dollars.

[d]Item 4 corresponds to the base analysis conditions.

For a particular source, the application of the generic efficiency may be incorrect. However, application of the generic efficiencies to sources for which there are no options available for use during strategy development indicates whether this lack of available options is responsible for some of the residual nonattainment.

The results of making the generic control efficiencies available during strategy development are shown in Table 6.4, line 1 of which presents results with the generic control efficiencies. For comparison, line 4 of the table presents results under base analysis conditions. The DPV costs were not calculated when generic control efficiencies were applied. The results show that the lack of control options in the cost and control file may contribute substantially to the residual nonattainment. However, before a more definitive conclusion could be drawn, it would be necessary to determine the SCC codes of those sources to which generic efficiencies were applied and ascertain whether the efficiencies of the controls are actually applicable to sources with those SCCs.

6.2.3 Weights for Coupling Coefficients

The procedure used to weight coupling coefficients is outlined in Section 3.2 (see Eqs. 3.2.3-3.2.6). One model run was made in the traditional rollback mode in which the weights of all coupling coefficients are equal (w_j = 1 for all sources, j). The nonattainment and national DPV costs for this run are presented in line 2 of Table 6.4. Using the traditional rollback assumption of equal weights would result in a reduction of about 15% in the number of residual nonattainment counties and an almost equal reduction in the national DPV cost over the seven years in the analysis period. These results are different from those of the base analysis, but as noted in Section 6.2.2 of Ref. 1, it cannot be said which system of weighting the coupling coefficients more adequately simulates the situation of interest within the context of a rollback model.

TABLE 6.5 Comparison of Growth Rates in Key Industries

	Growth Rate (% yr^{-1})		
	Base Analysis		
SIC	Maximum	Minimum	EPA
33	10.3	-0.1[a]	-2.92
49	6.2	2.4	1.64

[a]For Wyoming only. All other states had growth rates greater than or equal to +0.1% yr^{-1}.

6.2.4 Revised Growth Rates for Key Industries

As shown in Tables B.9-B.11 in Appendix B, SICs 3312 and 4911 (iron and steel and utility power plants, respectively) account for a substantial fraction of both the national DPV costs and the emission reductions achieved for all five of the standards investigated. The growth data used in these analyses had been developed in the early 1980s and thus probably represent projections based on economic conditions in the mid- to late 1970s. Given the changes in economic conditions in the last decade, it was decided to determine what effect the use of more current estimates of growth for these two industries would have on the results of the analysis. The EPA provided national estimates of the compound growth rates for these two two-digit SICs. Table 6.5 compares the range of state-specific growth rates used in this work with the national growth rates supplied by EPA. The growth rates used in the base analysis are always greater than the updated EPA growth rates. In fact, a net growth in primary metals, which includes reductions achieved for all five of the standards investigated. The growth data used in iron and steel, in the base analysis is replaced by a net decline when the EPA growth rate is used. These reduced growth rates would result in reductions in the projected concentrations and hence should result in less nonattainment and reduced costs when compared to the base analysis.

Line 3 in Table 6.4 shows the impact of using the EPA growth rates in place of the growth rates used in the base analysis. Seventeen additional counties are in attainment in 1995 and there is a reduction in national DPV costs of almost 25% over the analysis period. The number of 1989 initial nonattainment counties prior to the application of a control strategy is also reduced because growth in the two key SIC groups is reduced between the base year of 1978 and the first analysis year of 1989. As would be expected, these results indicate that the results of the study are quite sensitive to the growth rates assumed for utility power plants and primary metals.

REFERENCES

1. Smith, A.E., and K.L. Brubaker, *Costs and Air Quality Impacts of Alternative National Ambient Air Quality Standards for Particulate Matter, Technical Support Document*, Argonne National Laboratory Report ANL/EES-TM-229 (Jan. 1983).

2. Smith, A.E., K.L. Brubaker, and D.M. Hediger, Argonne National Laboratory, unpublished information (Aug. 1980).

3. *BACT/LAER Clearinghouse - A Compilation of Control Technology Determinations*, Vols. I, IIA, and IIB, unnumbered U.S. Environmental Protection Agency Report, Research Triangle Park, N.C. (May 1984).

APPENDIX A:

LIST OF ABBREVIATIONS

ATAC	After-tax annualized cost
BID	Background information document
BTAC	Before-tax annualized cost
CE	Cost-effectiveness
DPV	Discounted present value
EEA	Energy and Environmental Analysis, Inc.
EPA	U.S. Environmental Protection Agency
ICE	Incremental cost-effectiveness
LAER	Lowest achievable emissions rate
MCR	Maximum cost reduction
NAAQS	National ambient air quality standards
NAC	Nonattainment county
NSC	New-source control
NSPS	New-source performance standards
PM10	Particulate matter less than 10 microns
RACT	Reasonably available control technology
SCC	Source classification code
SIC	Standard Industrial Classification
TSP	Total suspended particulates

APPENDIX B:
SUMMARY OF SELECTED RESULTS

The tables in this appendix provide cost and selected environmental results for the scenarios investigated. A scenario is specified by an annual and/or a 24-hour standard for TSP, PM10, or both. In the tables, the scenarios are listed according to the following scheme:

POL1(ANN1,ST1) POL2(ANN2,ST2)

where:

POL1, POL2 = pollutant (TSP or PM10); POL2 is missing for single-pollutant scenarios,

ANN1, ANN2 = the value of the annual standard, if any, in $\mu g/m^3$, and

ST1, ST2 = the value of the short-term 24-hour standard, if any, in $\mu g/m^3$.

The annual standards are geometric means for TSP and arithmetic means for PM10. The 24-hour standards are second-highest observed values for TSP and expected values for PM10.

TABLE B.1 Nationwide TSP Emission Projections (10^3 tons/yr)[a]

Source Category	1978[b]	1989	1990	1991	1992	1993	1994	1995
Point	5041	4331	4293	4260	4230	4205	4183	4165
Nontraditional Fugitive	433	526	536	547	558	571	584	597
Effective Area[c]	230	234	235	235	235	236	236	237
Effective Total[c,d]	5705	5091	5064	5042	5025	5012	5003	4999

[a]Base conditions: a = 0.0, b = 0.5, α = 0.01, β = 0.01, γ = 0.0; standard growth rates; no control strategy applied.

[b]Nominal base-year.

[c]Entries represent "effective fraction" of area source emissions with $\alpha = \beta = 0.01$.

[d]Columns may not add exactly due to independent rounding of values.

TABLE B.2 Nationwide PM10 Emission Projections (10^3 tons/yr)[a]

Source Category	1978[b]	1989	1990	1991	1992	1993	1994	1995
Point	3668	3197	3174	3154	3137	3123	3112	3104
Nontraditional Fugitive	226	275	281	287	293	299	306	313
Effective Area[c]	60	63	63	64	64	64	65	64
Effective Total[c,d]	3955	3535	3518	3504	3494	3487	3483	3482

[a]Base conditions: a = 0.0, b = 0.5, α = 0.01, β = 0.01, γ = 0.0; standard growth rates; no control strategy applied.

[b]Nominal base-year.

[c]Entries represent "effective fraction" of area source emissions with $\alpha = \beta = 0.01$.

[d]Columns may not add exactly due to independent rounding of values.

TABLE B.3 Regional TSP Emission Projections (10^3 tons/yr)[a]

	Region[b]										
Year	I	II	III	IV	V	VI	VII	VIII	IX	X	National Total[c]
1978[d]	111	238	883	1440	1405	504	437	249	276	163	5705
1989	97	200	756	1348	1224	469	370	223	255	149	5091
1990	96	198	748	1349	1214	469	366	222	255	149	5064
1991	95	195	741	1352	1204	469	362	221	255	148	5042
1992	95	193	735	1356	1195	470	358	220	255	148	5025
1993	94	191	729	1362	1187	471	354	219	255	149	5012
1994	94	189	723	1370	1180	472	351	219	256	149	5003
1995	93	187	718	1379	1174	474	348	218	256	149	4999

[a]Base conditions: $a = 0.0$, $b = 0.5$, $\alpha = 0.01$, $\beta = 0.01$, $\gamma = 0.0$; standard growth rates; no control strategy applied.

[b]The states in each region are given in Appendix C.

[c]Rows may not add exactly due to independent rounding of values.

[d]Nominal base-year.

TABLE B.4 Regional PM10 Emission Projections (10^3 tons/yr)[a]

	Region[b]										
Year	I	II	III	IV	V	VI	VII	VIII	IX	X	National Total[c]
1978[d]	82	176	577	1015	1035	334	274	162	197	103	3955
1989	71	149	499	955	896	309	232	146	182	97	3535
1990	71	147	494	956	887	309	229	145	182	97	3518
1991	70	145	490	959	880	310	227	145	181	97	3504
1992	70	144	486	962	873	310	225	144	182	98	3949
1993	69	142	483	967	867	311	223	144	182	98	3487
1994	69	141	480	973	861	312	221	144	182	99	3483
1995	69	149	477	980	856	314	219	144	183	100	3482

[a]Base conditions: $a = 0.0$, $b = 0.5$, $\alpha = 0.01$, $\beta = 0.01$, $\gamma = 0.0$; standard growth rates; no control strategy applied.

[b]The states in each region are given in Appendix C.

[c]Rows may not add exactly due to independent rounding of values.

[d]Nominal base-year.

TABLE B.5 Sectional TSP Emission Projections (10^3 tons/yr)[a]

	Section[b]							
Year	Pacific	Mountain	Northern Midwest	Southern Midwest	North Central	Northeast	Southeast	National Total[c]
1978[d]	326	433	565	384	1324	923	1749	5705
1989	297	396	482	360	1154	781	1619	5091
1990	296	395	477	361	1145	773	1619	5064
1991	295	394	472	361	1136	764	1620	5042
1992	294	394	467	362	1127	757	1622	5025
1993	294	394	463	364	1120	750	1627	5012
1994	294	394	459	366	1113	743	1633	5003
1995	295	395	455	368	1108	737	1642	4999

[a]Base conditions: $a = 0.0$, $b = 0.5$, $\alpha = 0.01$, $\beta = 0.01$, $\gamma = 0.0$; standard growth rates; no control strategy applied.

[b]The states in each section are given in Appendix C.

[c]Rows may not add exactly due to independent rounding of values.

[d]Nominal base-year.

TABLE B.6 Sectional PM10 Emission Projections (10^3 tons/yr)[a]

	Section[b]							
Year	Pacific	Mountain	Northern Midwest	Southern Midwest	North Central	Northeast	Southeast	National Total[c]
1978[d]	221	297	347	255	985	620	1229	3955
1989	204	270	296	240	853	529	1144	3535
1990	203	269	292	240	845	524	1144	3518
1991	203	269	289	241	838	518	1146	3504
1992	203	269	287	242	831	514	1148	3494
1993	204	269	284	243	826	509	1152	3487
1994	204	269	282	244	820	505	1158	3483
1995	205	270	280	246	815	502	1164	3482

[a]Base conditions: $a = 0.0$, $b = 0.5$, $\alpha = 0.01$, $\beta = 0.01$, $\gamma = 0.0$; standard growth rates; no control strategy applied.

[b]The states in each section are given in Appendix C.

[c]Rows may not add exactly due to independent rounding of values.

[d]Nominal base-year.

TABLE B.7 Nationwide Costs and Attainment Status

Scenario	Number of Initial Nonattainment Counties[a,b] 1989	1992	1995	Cost of Strategy ($\$10^6$)[c,d] DPV[e]	BTAC[a] 1989	1992	1995	Number of 1995 Residual Nonattainment Counties[f]	Estimated DPV Cost for Reducation of Residual Nonattainment ($\$10^6$)[c,d,e]
TSP(75,150)	480	500	524	1884	667	617	582	288	2310
TSP(75,260)	275	281	285	1207	400	421	388	141	1211
PM10(50,150)	188	188	197	1015	323	341	313	87	844
PM10(65,250)	55	58	66	418	120	146	146	23	109
PM(50,150) TSP(90,-)	205	210	223	1120	401	366	346	101	990
PM10(65,250) TSP(90,-)	138	145	158	974	350	315	302	68	758

[a]Values were computed for each year from 1989 to 1995. Only three yearly values are tabulated.

[b]Initial nonattainment counties before application of control strategy.

[c]DPV = 1983 discounted present value; BTAC = before-tax annualized costs.

[d]Costs in first-quarter 1984 dollars.

[e]DPV is total of seven yearly values for 1989-1995.

[f]Residual nonattainment counties in 1995 after application of control strategy.

TABLE B.8 Nationwide Discounted Present Value ($$10^6$) and Emission Reductions Achieved (10^3 tons/yr), by Source Type[a]

		Source Type											
		Stack			Nontraditional Fugitive			Paved Municipal Roads			National Total[b]		
			ERA[c]			ERA			ERA			ERA	
Scenario	Year	DPV[c]	TSP	PM10	DPV	TSP	PM10	DPV	TSP	PM10	DPV	TSP	PM10
TSP(75,150)	1989	353	605	366	18	187	96	6	765	528	376	1556	990
	1992	243	554	340	14	197	100	4	782	539	262	1533	979
	1995	171	501	307	11	209	106	4	823	568	185	1533	981
TSP(75,260)	1989	211	374	222	11	123	63	4	569	393	226	1066	678
	1992	166	381	225	9	128	65	3	590	407	178	1098	697
	1995	114	348	207	7	145	74	2	612	423	124	1105	704
PM10(50,150)	1989	172	182	116	8	87	45	2	370	255	182	639	416
	1992	136	196	130	6	95	48	2	392	271	144	683	449
	1995	93	179	118	5	105	54	2	421	290	100	704	462
PM10(65,250)	1989	64	48	37	3	35	18	1	190	131	68	273	186
	1992	59	73	44	3	38	20	1	223	154	62	334	218
	1995	44	80	48	2	40	21	1	239	165	46	358	234
PM10(50,150) TSP(90,-)	1989	215	235	154	9	100	51	3	382	264	226	717	469
	1992	146	212	140	7	112	58	2	419	289	155	743	487
	1995	103	196	128	6	117	60	2	456	315	110	770	503
PM10(65,250) TSP(90,-)	1989	189	199	133	7	77	39	2	314	217	198	590	389
	1992	126	186	123	6	87	45	2	335	231	134	608	399
	1995	90	178	116	4	99	51	1	374	258	96	651	425

[a]Values were computed for each year from 1989 to 1995. Only three yearly values are tabulated.

[b]Rows may not add exactly due to independent rounding of values.

[c]DPV = discounted present value in first-quarter 1984 dollars; ERA = emissions reduction achieved.

TABLE B.9 1983 Discounted Present Value Costs for Major Source Categories, by Scenario and Year (10^6 first-quarter 1984 $)[a]

		TSP(75,150)				TSP(75,260)			
SIC	Category	1989	1992	1995	Total	1989	1992	1995	Total
-	Municipal Paved Roads	6	4	4	32	4	3	2	22
4911	Utility Power Plants	169	117	84	842	95	81	57	527
3312	Iron and Steel	55	37	25	269	38	27	18	190
1311	Crude Petroleum and Natural Gas	NR[b]	NR	NR	NR	10	7	5	50
1422	Crushed and Broken Limestone	5	4	3	26	2	2	1	11
1429	Other Crushed and Broken Stone	2	1	1	7	1	-[c]	-	3
1442	Construction Sand and Gravel	1	1	-	5	1	1	-	4
2041	Flour and Other Grain Mill Products	3	2	1	15	2	1	1	9
2621	Paper Mills, except Building Papers	6	4	3	30	2	1	1	8
2951	Paving Mixtures and Blocks	6	5	3	33	4	3	2	22
3241	Hydraulic Cement	6	5	4	36	5	4	3	29
3274	Lime	2	2	1	12	2	1	1	9
3281	Cut Stone and Stone Products	1	1	1	6	-	-	-	2
3295	Ground or Treated Minerals	5	3	2	24	4	3	2	19
3321	Gray Iron Foundries	5	3	2	25	3	2	1	13
3331	Primary Copper	1	1	1	6	1	1	-	5
3332	Primary Lead	-	-	-	-	-	-	-	-
3334	Primary Aluminum	-	-	-	1	-	-	-	-
4961	Steam Supply	6	4	3	30	5	4	2	26
5153	Wholesale Grain	6	4	3	31	3	2	2	15
All	National Total	376	262	185	1884	226	178	124	1207

TABLE B.9 (Cont'd)

SIC	Category	PM10(50,150) 1989	1992	1995	Total	PM10(65,250) 1989	1992	1995	Total
-	Municipal Paved Roads	2	2	2	14	1	1	1	7
4911	Utility Power Plants	46	43	30	293	21	15	10	107
3312	Iron and Steel	34	26	18	184	9	8	8	57
1311	Crude Petroleum and Natural Gas	37	25	16	179	19	24	16	147
1422	Crushed and Broken Limestone	1	-	-	3	-	-	-	2
1429	Other Crushed and Broken Stone	1	-	-	3	-	-	-	1
1442	Construction Sand and Gravel	-	-	-	3	-	-	-	1
2041	Flour and Other Grain Mill Products	-	-	-	2	-	-	-	-
2621	Paper Mills, except Building Papers	2	1	1	8	-	-	-	2
2951	Paving Mixtures and Blocks	3	2	1	14	1	1	1	5
3241	Hydraulic Cement	4	3	2	24	1	1	1	5
3274	Lime	1	1	1	8	1	-	-	3
3281	Cut Stone and Stone Products	-	-	-	2	-	-	-	1
3295	Ground or Treated Minerals	4	3	2	19	2	1	1	10
3321	Gray Iron Foundries	2	2	1	11	1	1	-	5
3331	Primary Copper	-	-	-	2	-	-	-	-
3332	Primary Lead	-	-	-	-	-	-	-	-
3334	Primary Aluminum	-	-	-	-	-	-	-	-
4961	Steam Supply	6	4	3	31	-	-	-	-
5153	Wholesale Grain	2	1	1	9	-	-	-	3
All	National Total	182	144	100	1015	68	62	46	418

TABLE B.9 (Cont'd)

		PM10(50,150) TSP(90,-)				PM10(65,250) TSP(90,-)			
SIC	Category	1989	1992	1995	Total	1989	1992	1995	Total
-	Municipal Paved Roads	3	2	2	15	2	2	1	12
4911	Utility Power Plants	70	49	35	349	65	45	32	321
3312	Iron and Steel	42	28	19	202	39	25	18	188
1311	Crude Petroleum and Natural Gas	37	25	16	179	37	25	16	179
1422	Crushed and Broken Limestone	1	-	-	3	1	-	-	3
1429	Other Crushed and Broken Stone	1	-	-	3	-	-	-	2
1442	Construction Sand and Gravel	1	-	-	3	-	-	-	2
2041	Flour and Other Grain Mill Products	-	-	-	2	-	-	-	1
2621	Paper Mills, except Building Papers	2	1	1	8	-	-	-	2
2951	Paving Mixtures and Blocks	3	2	2	16	2	2	1	12
3241	Hydraulic Cement	5	4	2	25	4	3	2	22
3274	Lime	1	1	1	8	1	1	1	7
3281	Cut Stone and Stone Products	-	-	-	2	-	-	-	1
3295	Ground or Treated Minerals	4	3	2	20	3	2	2	16
3321	Gray Iron Foundries	3	2	1	13	2	1	1	11
3331	Primary Copper	-	-	-	2	-	-	-	1
3332	Primary Lead	-	-	-	-	-	-	-	-
3334	Primary Aluminum	-	-	-	-	-	-	-	-
4961	Steam Supply	6	4	3	31	3	2	2	15
5153	Wholesale Grain	2	1	1	9	1	1	-	5
All	National Total	226	155	110	1120	198	134	96	974

[a]Totals are sums of the seven yearly values for 1989-1995. Values were computed for each year from 1989 to 1995; only three yearly values are tabulated.

[b]NR = not reported; the SIC was not on the list of standard SICs and did not contribute 3% or more of the national total DPV.

[c]- = a rounded DPV <$1,000,000.

TABLE B.10 TSP Emission Reductions for Major Source Categories, by Scenario and Year (10^3 tons/yr)[a]

		TSP(75,150)			TSP(75,260)		
SIC	Category	1989	1992	1995	1989	1992	1995
-	Municipal Paved Roads	765	782	823	569	590	612
4911	Utility Power Plants	383	358	335	195	215	215
3312	Iron and Steel	120	109	101	103	93	84
1311	Crude Petroleum and Natural Gas	NR[b]	NR	NR	3	3	2
1422	Crushed and Broken Limestone	12	12	11	6	7	7
1429	Other Crushed and Broken Stone	5	5	4	4	4	4
1442	Construction Sand and Gravel	2	2	2	2	2	2
2041	Flour and Other Grain Mill Products	4	4	3	2	2	2
2621	Paper Mills, except Building Papers	7	7	8	3	3	3
2951	Paving Mixtures and Blocks	19	18	18	12	12	12
3241	Hydraulic Cement	38	46	45	35	42	39
3274	Lime	5	4	6	4	4	3
3281	Cut Stone and Stone Products	5	4	4	2	2	2
3295	Ground or Treated Minerals	25	25	23	22	20	19
3321	Gray Iron Foundries	2	2	1	1	1	1
3331	Primary Copper	3	3	2	3	3	2
3332	Primary Lead	-[c]	-	-	-	-	-
3334	Primary Aluminum	3	3	3	1	1	1
4961	Steam Supply	4	4	4	4	4	4
5153	Wholesale Grain	13	12	11	7	7	7
All	National Total	1556	1533	1533	1066	1098	1105

TABLE B.10 (Cont'd)

SIC	Category	PM10(50,150) 1989	1992	1995	PM10(65,250) 1989	1992	1995
-	Municipal Paved Roads	370	392	421	190	223	239
4911	Utility Power Plants	67	86	84	14	34	31
3312	Iron and Steel	57	56	52	15	21	25
1311	Crude Petroleum and Natural Gas	5	4	4	3	4	4
1422	Crushed and Broken Limestone	2	2	2	-	-	-
1429	Other Crushed and Broken Stone	4	4	4	1	4	3
1442	Construction Sand and Gravel	1	1	1	-	1	1
2041	Flour and Other Grain Mill Products	1	1	1	-	-	-
2621	Paper Mills, except Building Papers	3	3	2	1	1	1
2951	Paving Mixtures and Blocks	7	7	9	2	3	4
3241	Hydraulic Cement	21	25	24	7	7	13
3274	Lime	4	4	3	3	3	2
3281	Cut Stone and Stone Products	2	2	2	1	1	1
3295	Ground or Treated Minerals	21	19	17	18	16	14
3321	Gray Iron Foundries	1	1	1	-	-	-
3331	Primary Copper	1	1	2	1	1	1
3332	Primary Lead	-	-	-	-	-	-
3334	Primary Aluminum	1	1	1	-	-	-
4961	Steam Supply	2	2	2	1	1	1
5153	Wholesale Grain	4	4	4	1	1	1
All	National Total	639	683	704	273	334	358

TABLE B.10 (Cont'd)

SIC	Category	PM10(50,150) TSP(90,-1) 1989	1992	1995	PM10(65,250) TSP(90,-1) 1989	1992	1995
-	Municipal Paved Roads	382	419	456	314	335	374
4911	Utility Power Plants	94	93	95	89	86	85
3312	Iron and Steel	74	67	62	56	58	59
1311	Crude Petroleum and Natural Gas	5	4	4	5	4	4
1422	Crushed and Broken Limestone	2	2	2	2	2	2
1429	Other Crushed and Broken Stone	4	4	4	4	4	3
1442	Construction Sand and Gravel	1	1	2	1	1	1
2041	Flour and Other Grain Mill Products	1	1	1	1	1	1
2621	Paper Mills, except Building Papers	3	3	2	2	2	2
2951	Paving Mixtures and Blocks	8	8	10	7	7	7
3241	Hydraulic Cement	29	29	27	23	23	24
3274	Lime	4	4	3	4	3	3
3281	Cut Stone and Stone Products	2	2	2	1	1	1
3295	Ground or Treated Minerals	22	19	17	20	18	16
3321	Gray Iron Foundries	1	1	1	1	-	-
3331	Primary Copper	1	1	2	1	1	1
3332	Primary Lead	-	-	-	-	-	-
3334	Primary Aluminum	1	1	1	-	1	1
4961	Steam Supply	3	3	3	3	2	2
5153	Wholesale Grain	4	4	4	3	2	2
All	National Total	717	743	770	590	608	651

[a]Values were computed for each year from 1989 to 1995; only three yearly values are tabulated.

[b]NR = not reported; the SIC was not on the list of standard SICs and did not contribute 3% or more of the national total DPV.

[c]- = a rounded TSP emission reduction less than 1000 tons/yr.

TABLE B.11 PM10 Emission Reductions for Major Source Categories, by Scenario and Year (10^3 tons/yr)[a]

		TSP(75,150)			TSP(75,260)		
SIC	Category	1989	1992	1995	1989	1992	1995
-	Municipal Paved Roads	528	539	568	393	407	423
4911	Utility Power Plants	217	203	188	110	117	119
3312	Iron and Steel	66	60	55	54	49	44
1311	Crude Petroleum and Natural Gas	NR[b]	NR	NR	3	3	2
1422	Crushed and Broken Limestone	7	7	7	4	4	4
1429	Other Crushed and Broken Stone	2	2	2	1	1	1
1442	Construction Sand and Gravel	1	1	1	1	1	1
2041	Flour and Other Grain Mill Products	3	3	3	2	2	1
2621	Paper Mills, except Building Papers	5	5	5	1	1	1
2951	Paving Mixtures and Blocks	8	9	9	6	6	6
3241	Hydraulic Cement	20	27	26	18	25	23
3274	Lime	4	3	4	3	3	2
3281	Cut Stone and Stone Products	4	3	3	1	1	1
3295	Ground or Treated Minerals	18	16	15	16	14	13
3321	Gray Iron Foundries	1	1	1	1	1	1
3331	Primary Copper	1	1	1	1	1	1
3332	Primary Lead	-[c]	-	-	-	-	-
3334	Primary Aluminum	1	1	2	-	1	1
4961	Steam Supply	3	4	3	2	2	2
5153	Wholesale Grain	11	12	11	6	6	5
All	National Total	990	979	981	678	697	704

TABLE B.11 (Cont'd)

SIC	Category	PM10(50,150) 1989	1992	1995	PM10(65,250) 1989	1992	1995
-	Municipal Paved Roads	255	271	290	131	154	165
4911	Utility Power Plants	34	52	50	10	14	13
3312	Iron and Steel	35	35	32	9	14	15
1311	Crude Petroleum and Natural Gas	5	4	4	3	4	4
1422	Crushed and Broken Limestone	1	1	1	-	-	-
1429	Other Crushed and Broken Stone	1	1	1	-	1	1
1442	Construction Sand and Gravel	1	1	1	-	-	-
2041	Flour and Other Grain Mill Products	1	-	-	-	-	-
2621	Paper Mills, except Building Papers	1	1	1	1	-	-
2951	Paving Mixtures and Blocks	4	4	4	1	2	2
3241	Hydraulic Cement	12	13	12	4	4	8
3274	Lime	3	3	3	3	2	2
3281	Cut Stone and Stone Products	1	1	1	1	1	1
3295	Ground or Treated Minerals	16	14	12	14	12	11
3321	Gray Iron Foundries	-	-	-	-	-	-
3331	Primary Copper	-	-	1	-	-	-
3332	Primary Lead	-	-	-	-	-	-
3334	Primary Aluminum	-	-	1	-	-	-
4961	Steam Supply	2	2	2	-	-	-
5153	Wholesale Grain	3	3	3	1	1	1
All	National Total	416	449	462	186	218	234

TABLE B.11 (Cont'd)

		PM10(50,150) TSP(90,-)			PM10(65,250) TSP(90,-)		
SIC	Category	1989	1992	1995	1989	1992	1995
-	Municipal Paved Roads	264	289	315	217	231	258
4911	Utility Power Plants	57	56	55	53	52	50
3312	Iron and Steel	44	40	37	35	34	35
1311	Crude Petroleum and Natural Gas	5	4	4	5	4	4
1422	Crushed and Broken Limestone	1	1	1	1	1	1
1429	Other Crushed and Broken Stone	1	1	1	1	1	1
1442	Construction Sand and Gravel	1	1	1	1	1	1
2041	Flour and Other Grain Mill Products	1	1	1	-	-	-
2621	Paper Mills, except Building Papers	1	1	1	1	1	1
2951	Paving Mixtures and Blocks	4	4	5	4	4	4
3241	Hydraulic Cement	16	15	14	14	13	13
3274	Lime	3	3	3	3	3	3
3281	Cut Stone and Stone Products	1	2	1	1	1	1
3295	Ground or Treated Minerals	16	14	12	15	13	12
3321	Gray Iron Foundries	1	-	-	-	-	-
3331	Primary Copper	-	1	1	-	-	1
3332	Primary Lead	-	-	-	-	-	-
3334	Primary Aluminum	1	1	1	-	1	1
4961	Steam Supply	2	2	2	2	2	2
5153	Wholesale Grain	4	3	3	2	2	2
All	National Total	469	487	503	389	399	425

[a]Values were computed for each year from 1989 to 1995; only three yearly values are tabulated.

[b]NR = not reported; the SIC was not on the list of standard SICs and did not contribute 3% or more of the national total DPV.

[c]- = a rounded PM10 emission reduction less than 1000 tons/yr.

TABLE B.12 Regional Discounted Presented Value Costs ($\$10^6$) and Attainment Status, by Region[a,b]

Scenario	I DPV	I NAC	II DPV	II NAC	III DPV	III NAC	IV DPV	IV NAC	V DPV	V NAC
TSP(75,150)	57	22/13	38	13/7	264	43/28	201	88/32	791	134/68
TSP(75,260)	5	10/2	18	5/1	210	29/10	107	30/19	490	72/26
PM10(50,150)	2	7/0	11	3/1	144	16/4	84	15/9	318	45/12
PM10(65,250)	0	0/0	0	0/0	2	5/0	14	3/1	123	15/4
PM10(50,150) TSP(90,-)	4	7/1	11	3/1	182	17/5	89	24/12	364	52/15
PM10(65,250) TSP(90,-)	2	2/1	<1	1/0	172	13/4	54	21/6	351	35/13

Scenario	VI DPV	VI NAC	VII DPV	VII NAC	VIII DPV	VIII NAC	IX DPV	IX NAC	X DPV	X NAC
TSP(75,150)	65	46/29	175	50/16	93	31/22	151	46/37	49	51/36
TSP(75,260)	48	29/17	82	28/8	70	17/11	145	39/27	32	31/20
PM10(50,150)	46	25/16	13	16/3	39	13/3	332	34/23	31	24/16
PM10(65,250)	14	11/5	2	5/0	31	4/1	230	15/7	10	9/5
PM10(50,150) TSP(90,-)	46	27/17	15	19/3	47	14/4	335	34/26	32	27/17
PM10(65,250) TSP(90,-)	39	17/8	9	13/3	42	11/3	298	25/22	12	22/8

[a]DPV = discounted present value in first-quarter 1984 dollars (totals are for all seven years, 1989-1995). NAC = number of nonattainment counties; NAC entries give (Maximum number of initial NAC for the years 1989-1995, inclusive)/(Number of 1995 residual NAC).

[b]The states in each region are listed in Appendix C.

TABLE B.13 Sectional Discounted Present Value Costs ($\$10^6$) and Attainment Status, by Section[a,b]

Scenario	Pacific		Mountain		Northern Midwest		Southern Midwest		North Central		Northeast		Southeast	
	DPV	NAC	DPV	NAC	DPV	NAC	DPV	NAC	DPV	NAC	DPV	NAC	DPV	NAC
TSP(75,150)	125	63/44	177	73/57	187	66/21	55	36/23	780	121/63	341	58/38	219	108/42
TSP(75,260)	107	41/25	148	49/37	83	36/9	39	25/13	489	66/25	221	33/10	120	41/22
PM10(50,150)	271	32/23	141	43/23	13	20/3	36	21/12	318	42/12	144	19/2	97	22/12
PM10(65,250)	173	14/7	100	17/8	2	6/0	11	8/3	123	14/4	2	5/0	14	3/1
PM10(50,150) TSP(90,-)	272	33/25	151	46/26	16	23/3	37	23/13	364	49/15	183	19/4	102	32/15
PM10(65,250) TSP(90,-)	232	27/16	128	35/20	9	14/3	31	13/5	351	34/13	170	10/3	58	27/8

[a]DPV = discounted present value in first-quarter 1984 dollars (totals are for all seven years, 1989-1995). NAC = number of nonattainment counties; NAC entries give (maximum number of initial NAC for the years 1989-1995 inclusive)/(number of 1995 residual NAC).

[b]The states in each section are listed in Appendix C.

TABLE B.14 Estimated Nationwide Costs, Including Reduction of Residual Nonattainment[a,b]

Scenario	BTAC(10^6\$/yr) 1989	1992	1995	DPV(10^6\$) 1989	1992	1995	Total
TSP(75,150)	1375	1385	1430	776	587	456	4193
TSP(75,260)	761	824	851	430	349	271	2418
PM10(50,150)	572	622	640	323	264	204	1859
PM10(65,250)	151	182	193	85	77	61	528
PM10(50,150) TSP(90,-)	690	694	736	390	294	234	2110
PM10(65,250) TSP(90,-)	568	567	606	321	240	193	1733

[a]BTAC = before-tax annualized cost; DPV = 1983 discounted present value (totals are for all seven years, 1989-1995).

[b]All costs are in first-quarter 1984 dollars; values were computed for each year from 1989 to 1995 (only three yearly values are tabulated).

APPENDIX C:

REGIONS AND SECTIONS OF THE U.S.

Table C.1 lists the states by EPA region as used in the preparation of regional reports. These are the standard EPA administrative regions. Table C.2 lists the states by section as defined for this work.

TABLE C.1 States by EPA Region

Region	States	Region	States
I	Connecticut Maine Massachusetts New Hampshire Rhode Island Vermont	VI	Arkansas Louisiana New Mexico Oklahoma Texas
II	New Jersey New York Puerto Rico Virgin Islands[a]	VII	Iowa Kansas Missouri Nebraska
III	Delaware District of Columbia Maryland Pennsylvania Virginia West Virginia	VIII	Colorado Montana North Dakota South Dakota Utah Wyoming
IV	Alabama Florida Georgia Kentucky Mississippi North Carolina South Carolina Tennessee	IX	American Samoa[a] Arizona California Guam[a] Hawaii Nevada
V	Illinois Indiana Michigan Minnesota Ohio Wisconsin	X	Alaska Idaho Oregon Washington

[a]Not included in this analysis.

TABLE C.2 States by Section

Section and States	Section and States
1. Pacific	5. North Central
Alaska	Illinois
California	Indiana
Hawaii	Michigan
Oregon	Ohio
Washington	Wisconsin
2. Mountain	6. Northeast
Arizona	Connecticut
Colorado	Maine
Idaho	Massachusetts
Montana	New Hampshire
Nevada	New Jersey
New Mexico	New York
Utah	Pennsylvania
Wyoming	Rhode Island
	Vermont
3. Midwest	7. Southeast
Iowa	Alabama
Kansas	Delaware
Minnesota	District of Columbia
Missouri	Florida
Nebraska	Georgia
North Dakota	Kentucky
South Dakota	Maryland
	Mississippi
	North Carolina
4. South Midwest	Puerto Rico
Arkansas	South Carolina
Louisiana	Tennessee
Oklahoma	Virginia
Texas	West Virginia

X